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THE DESIGN OF AN ENVIRONMENTAL INDEX OF SUSTAINABLE FOOD CONSUMPTION: A PILOT STUDY USING SUPERMARKET DATA

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Abstract

Monitoring of the environmental impacts of consumption is necessary for the evaluation of current performance and to support the understanding of how initiatives for change can be implemented. We discuss design issues and methodology for an Environmentally Sensitive Shopper (ESS) index to measure the environmental sustainability of food consumption at the household level. The ESS index is based on revealed consumer preferences and tested with scanner data provided by the largest UK food retailer. As a pilot illustration of the methodology we use of the index to identify environmentally critical periods during the calendar year.

Keywords: Sustainable consumption, Sustainability index, Revealed preferences, Food.

JEL codes: C43, Q56

INTRODUCTION

Behavioural change by households is increasingly anticipated to make an important contribution to the reduction of greenhouse gasses (GHG) and other emissions (Schor, 2005; Jackson, 2006). As a result, monitoring of the environmental impacts of consumption at the household level is necessary to evaluate current performance and to support the understanding of how initiatives for change can be implemented (OECD, 1999). Among the goods and services that make up household consumption, food, private transport, and housing are consistently identified as the most important categories in lifecycle environmental inventories of household consumption expenditures. Particularly food is at the core of the discussion of sustainable consumption (see e.g. WWF, 2009; FAO, 2006), being responsible for 20-30% of the overall environmental emissions from household consumption (Tukker *et al*., 2010).

In order to aid in setting priorities for public decision making, further research is needed not only into the magnitude of the environmental impacts of food consumption but also, more importantly, into how this impact could be reduced. Specifically, it is necessary to analyse how food products are combined in more and less sustainable food patterns and how changes in these food patterns as part of modern consumption activities can reduce the environmental impact of households. Furthermore, this information needs to be presented at a detailed level to investigate environmental improvement opportunities from retail innovation and behavioural change. Presently such analysis is restricted by the lack of a tool to measure the environmental impact of food consumption at household level (see OECD, 1999; UNEP, 2008). The implication of this state of affairs is the inability to assess changes in the environmental impact of actual food consumption over time or between consumers, limiting in turn the *ex-ante* analysis of environmental improvement interventions at the retail stage. In addition, an *ex-post* cost-effectiveness of policies targeting consumer behaviour cannot be established due to the absence of a reference point for the environmental performance.

The literature presents a selection of sustainability assessment tools varying in scope and methodological approach (see e.g. Gasparatos and Scolobig, 2012; and Singh *et al.*, 2009). However, such tools are commonly characterised by a production perspective (Spangenberg *et al*. 2002; Ness *et al.*, 2007; Singh *et al.*, 2009), providing information on physical flows at either a detailed (product) or a highly aggregated territorial level (regional or national) (e.g. Virtanen *et al.*, 2011). Well established examples are lifecycle assessment, which measure the environmental damage (in GHG) produced over the life of a good; material flow analysis, which assesses the material intensity of production; and environmentally extended input-output models, which compute the flow of emissions along supply and production chains. The concept of food-miles (e.g. Pretty *et al.*, 2005) also fits in this category as it uses emissions from transportation, although food miles is generally proven to be unimportant unless the supply chain requires emissions from aviation (Jungbluth *et al***.,** 2000).

A second category of tools integrates environmental (physical flows) with socio-economic variables but, again, in order to evaluate the supply side (production) of the market. The assessment is usually at the regional or national level (e.g. Dietz and Neumayer, 2006) although examples of integrated tools for firms also exist (see for instance the overview by Del Prado *et al.*, 2011). In contrast, consumption-based emission accounting is a recent development and few such studies appear in the literature. These existing studies use top-down input-output methods with the objective to juxtapose consumption and producer emissions in order to demonstrate the effects of emissions associated with international trade, especially for GHG (e.g., Wiedmann, 2009; Kerkhof *et al.*, 2009; Kastner *et al.*, 2011).

Thus the environmental literature has yet to propose a tool to measure environmentally sustainable food and non-food consumption at the household level, surprising as this may appear. An important explanation is the restricted availability of data on environmental impact at the household level, making existing approaches either: product-based, focusing on a single aspect of the supply chain (e.g. the food miles concept); or based on stated behaviour, using factor analysis of (consumer-level) survey data to determine the environmental propensity of consumers (e.g. Nie and Zepeda, 2011). The latter indicators reflect the stated beliefs and habits of those included in the survey rather than their actual behaviour[1]. The implication is that consumers could be labelled as "environmentally concerned" whilst being heavy polluters (Kemp *et al*., 2010). Indeed, psychological studies reveal significant discrepancies between explicit attitudes (what people say) and implicit attitudes (underlying preferences) (e.g. Beattie *et al*., 2009).

Against this background the present paper develops an indicator of sustainable household consumption: the Environmentally Sensitive Shopper (ESS) index, the structure of which is summarised in Figure 1. Compared with existing alternatives (e.g., the ecological footprint or the carbon footprint), this indicator has several innovative aspects. First, as it is based on revealed consumer preferences, it avoids the hypothetical bias mentioned above. Second, the design combines insights from different disciplines, particularly economics, sociology, and sustainability science (see Figure 1). Finally, the focus of this index is specifically on the consumption of households, whose GHG emissions are a crucial component for sustainability targets: while suppliers effectively emit GHG, the demand side plays a major role in requesting them through their consumption process.

This article discusses the methodology and data basis of the ESS index and presents its use through a pilot application for the UK, where a large share of the environmental footprint of households is attributed to food purchases (Druckman *et al*., 2008, 2011). Section 2 introduces the rationale of the indicator starting from the individual consumer perspective and subsequently extending it to an aggregated level. The indicator is presented in a basic and in

[1] See also Southerton *et al*. (2011) for a discussion of the significance of analysing food consumption through behaviours revealed by time-use patterns as opposed to stated attitudes.

more elaborated versions taking into account consumer habits and social norms. The pilot implementation of the ESS index is described in section 3, with a description of the scanner data used in the analysis and a discussion of the food categories included in the ESS index for the UK pilot exercise. Section 4 discusses the validity and reliability of the food ESS and presents results of a range of tests that supports the effectiveness of this index as an indicator of sustainable food consumption. Section 5 describes the implications of the findings of this article, and section 6 concludes.

1. DESIGN ISSUES AT THE LEVEL OF THE INDIVIDUAL CONSUMER

A common working definition equates sustainable consumption with “the use of services and related products which responds to basic needs and brings a better quality of life while minimising the use of natural resources and toxic materials as well the emission of waste and pollutants over the life cycle of the service or products so as not to jeopardise the needs of future generations” (OECD, 1999). Another useful perspective offered by the literature is that sustainable consumption is an *ethical* practice of consuming *differently* to reduce environmental impacts. It follows that sustainable consumption is a matter of both consuming differently reducing the environmental impact of what is consumed (changing the composition of the basket) and of consuming less in terms how much is consumed (reducing volumes) (Evans, 2011). The design of the index should address both these aspects and thus account for both the environmental impact of the composition of food consumption and the environmental impact of the quantity of consumption at the household level.

To derive a general micro-economic definition of sustainable consumption, imagine a consumer i who shops at a time t in a retailer with J food categories. In each category, this consumer makes two consecutive choices. First, she will decide whether to purchase a product within a specific food category. Second, the consumer will determine the quantity of food in category j to buy. Let Q_{ij} denote quantity purchased in case of a positive outcome in step one. Consumer *i*'s total food consumption, *E*, can then be written in quantity terms as $E_i = \sum_{j=1}^{J} I_{ij} \cdot Q_{ij}$ and in expenditure terms as $X_i = \sum_{j=1}^{J} \left[\left(I_{ijt} \cdot Q_{ijt} \right) \cdot p_{ijt} \right]$ where *p* is price. Total emissions, *M*, from this level of consumption would then be

$$M_{ij} = \sum_{j=1}^{J} \left\{ \left[\left(I_{ij} \cdot Q_{ij} \right) \cdot p_j \right] \cdot envimpact_j \right\} \qquad (1)$$

where $envimpact_j$ denotes the life cycle environmental impact demanded by consumer *i* to consume food product category *j* (in CO_2 equivalent/£).

Exact knowledge of $envimpact_j$ for all food categories $j \in J$ would perfectly identify the carbon footprint of each individual consumer. However, due to the uncertainty and incomparability of LCA estimates this approach is not feasible at this time. Retailers store a variety of different products from different manufacturers, but only know the footprint of own-labelled goods. Knowledge of the footprint of suppliers would not help: incomparability stems from the usage of different functional units, unit processes and different impact categorizations (Emblemsvåg and Bras, 1999). An further issue is that sales are recorded in expenditure terms, while the footprint is measured over units of weight or volume (e.g. CO_2eq/kg). In addition, there are difficulties in separating emissions strictly pertaining to demand (i.e. purely associated to end use and related services) from those associated with supply.

Since implementation of eqn. (1) is not feasible in practice, as the first step in the design of an indicator we propose to focus on a selection of critical categories out of the total of *J* food categories (Figure 1). Food consumption in OECD countries spans over many different products; however, its environmental impact is limited to a small number of key "dirty" categories (Kramer *et al*., 1999; Kim and Neff, 2009). Hence, there is no need for an exhaustive view of total food consumption as long as we observe expenditures for these key items. Thus we distinguish a subset $C \subseteq J$ of "clean" (environmentally friendly) and a subset $D \subseteq J$ of "dirty" (environmentally unfriendly) food product categories with $C \cap D = \emptyset$.

The second step is to measure a consumer's demand within each of these selected food categories. For a utility-maximizing consumer, an individual's demand for such a food category is fully represented by its share in this person's expenditures (Deaton and Muellbauer, 1980). Let w_{ij} denote the share of expenditure allocated to category j. This measure of consumption incorporates information on quantity consumed (an important feature of sustainability, see Fiala 2008), while ensuring that the composition of the shopping basket in taking into account; rich households will spend more in most categories in absolute terms but this may nevertheless represent a smaller share of their food budget. To ensure consistency in the calculation, for the dirty food categories D, the share of food expenditure in these categories is transformed by subtracting the observed value from unity. Thus, using the superscript c for a "clean" and d for a "dirty" food product category, consumption for category j at time t for consumer i, C_{ijt}, is given by:

$$
\begin{aligned}
C_{ijt}^{c} &= w_{ijt}^{c} \\
C_{ijt}^{d} &= (1 - w_{ijt}^{d})
\end{aligned}
\qquad (2)
$$

for a clean category and a dirty category respectively. In the remainder of section 2 we omit the superscripts c and d for simplicity.

Next, expenditures by category are to be related to environmental impact. A first and straightforward approach is to assume that environmental sustainability is proportional with C_{ijt}. A second approach is to take a sociological perspective i.e. to use the social norm (see Figure 2). For this we propose to use thresholds by food category based on the most frequently observed consumption behaviour (the mode) in each food category,. Social norms can be strategic in the design of instruments to address the sustainability of consumption (Kallbekken *et al.*, 2010), because they indicate a reference that can shift individuals consuming excessively towards the mode of the population. Consequently, a threshold based on the social norm represents a relative concept of sustainability, where "sustainable consumption is intended as "consuming better" given present observed practices rather than based on sustainable consumption in absolute terms based on environmental footprint and biocapacity. This approach is consistent with the ethical implications of sustainable consumption (see Evans, 2011): environmental improvements in consumption require both a reduction in quantity consumed and a need to change the composition of the whole food basket, hence category-specific thresholds. Consequently, according to this second approach individual *i* is considered a sustainable consumer for category *j* if her level of consumption, C_{ijt} (see eqn. 2) is in line with the social norm of the specific categories[2].

Based on the above we can now denote the environmental sustainability, S_{ijt}, of consumption for category *j*, C_{ijt}, as follows:

$$\begin{aligned} & S_{ijt} = 1 \quad \text{if } C_{ijt} \geq C_{jt}^{\text{mod}us} \quad \text{and} \quad C_{jt}^{\text{mod}us} \neq 0 \\ & S_{ijt} = 0 \quad \text{if } C_{ijt} \leq C_{jt}^{\text{mod}us} \quad \text{and} \quad C_{jt}^{\text{mod}us} \neq 0 \\ & S_{ijt} = C_{ijt} \quad \text{otherwise} \end{aligned} \tag{3}$$

where C^{modus} indicates the social norm of food category *j*. Note that C^{modus} will take on the value of zero if the assessment excludes the social norm. It follows that for the case with the social norm the resulting value of S_{ijt} will be binary (either 1 or 0) whereas for the version without the norm this will be continues on the [0,1] interval.

In the approach above, a comparison across food categories *j* is difficult if mean and variance of C_{ijt} differ substantially. This is a particularly important problem in food consumption, where habits account for different levels of consumption and resistance to change (e.g. Sanne, 2002; Southerton *et al*., 2004). Thus, a marginal change in consumption appears negligible for food products with high levels of consumption (e.g. staple foods), and extremely high in categories where consumption is low. Consequently, consumption as defined above would underestimate or overestimates changes when the initial level of

[2] Given the formulation of C_{ijt} in eqn (2) this means that individual *i* is considered a sustainable consumer whenever her expenditure share is above the mode for "clean" categories and below for "dirty" categories.

consumption is high or low, respectively. To account for habits the procedure outlined above was also executed after normalising the expenditures (see Diaz-Balteiro and Romero, 2004). This transformation corresponds to:

$$C_{ijt}^{habit\ correctedt} = \frac{C_{ijt} - \min(C_{ijt})}{\max(C_{ijt}) - \min(C_{ijt})} \qquad (4)$$

where *max*(·) and *min*(·) indicate the historical minimum and maximum for category *j*. The maximum and the minimum correspond to the highest and lowest value observed in a time series for each of the categories. By construction, the minimum and maximum values are to be intended as dynamic. This means that as new minima or maxima are reached over time, the habit correction needs to be adjusted.

2. AGGREGATION INTO AN ESS INDEX

In order to provide a single economy-wide overview of sustainable consumption in a given time period (e.g. weeks, months), individual sustainable consumption needs to be aggregated across two dimensions: consumers and categories. This aggregate measure is the ESS index. The procedure includes two steps:

- *Aggregation across consumers*: calculate the average level of consumption across the population for each category j, obtaining C+D time series;
- *Aggregation across categories*: group the result for the C+D categories into a single value.

While the first step is straightforward, the aggregation in the second step can have different forms depending on the aggregating function chosen, which entails slightly different definitions of sustainable consumption.

In the first step, the aggregation across consumers is food category specific. Environmental sustainability at the aggregate level for category *j* at time *t* simply equals to the mean for the population of *N* consumers in the market for a specific category j:

$$\bar{S}_{jt} = \frac{\sum_{i=1}^{N} S_{ijt}}{N} \tag{5}$$

The second step defines the ESS index by aggregating sustainable consumption over the *C+D* categories considered. This aggregation can take different forms. As a first approach, sustainable consumption can be defined as the sum of sustainable consumption in each category, which equals average individual sustainability:

$$ESS_t = \sum_{j=1}^{C} \bar{S}_{jt}^{c} + \sum_{j=1}^{D} \bar{S}_{jt}^{d} \tag{6}$$

Alternatively, sustainable consumption can be defined as the average across all categories. A first option is to calculate the *arithmetic mean* of sustainable consumption across categories:

$$ESS_t\,(am) = \frac{\sum_{j=1}^{C} \bar{S}_{jt}^{c} + \sum_{j=1}^{D} \bar{S}_{jt}^{d}}{(C+D)} \tag{7}$$

Equation (7) weights the categories equally. Aggregation could instead use the *geometric mean* to account for differences in numerical range across different food categories. This aggregation corresponds to:

$$ESS_t\,(gm) = \exp\left(\frac{\sum_{C} \ln \bar{S}_{jt}^{c} + \sum_{D} \ln \bar{S}_{jt}^{d}}{(C+D)} \right) \tag{8}$$

3. A PILOT EXERCISE: THE UK FOOD ESS INDEX

This section lays the ground for the analysis of the performance of the different versions of this macro-style ESS index through a pilot study. This empirical exercise is not meant to define a final version of the index design, but just to test its capabilities to measure the sustainability of a food basket. Thus the remainder of the paper calculates and compares the alternatives ESS indices with data on UK food consumption over a two-year period.

3.1. The selection of "clean" and "dirty" food product categories

The previous section presented the design of the ESS index with no particular definition of what enters (or should enter) the food basket. The pilot study builds on the expenditure levels for three food and drinks categories that have been recognised widely as less sustainable in the UK: total meat, red meat, and bottled water; and three categories considered sustainable: total fruit and vegetables (F&V), organic F&V, and online food shopping. These categories were derived from Defra's (2010) 'Food 2030' (Defra's 2030 roadmap) and Sustain's (2007) 'Eat Well and Save the Planet' reports, both of which produce a set of consumer-oriented guidelines on more sustainable food consumption. While each report places different emphasis on the details of what represents a more sustainable form of consumption, consensus is presented across the principles of: eating less meat, particularly red meat, and more F&V; selecting fair-trade, seasonal, local and organic products; drink tap rather than bottled water; and reduce car travel for the purpose of food shopping. While the sustainability of organic food production is controversial (Magkos *et al*., 2003; Williams, 2002), organic F&V is included for consistency with these publications. Finally, seasonality is also important (see Garnett 2008), but it is only imperfectly captured by sales of F&V; while the dataset has scarce information on the country of origin.

The pilot index includes **meat** and **red meat** consumption because of their very high carbon footprint (Williams *et al*., 2006; D'Silva and Webster, 2010). These categories refer to budget spent on any meat (e.g. fresh, frozen, canned, ready-made, or freshly cooked). **F&V** and **organic F&V** have been included due to their low carbon footprint (Williams *et al*., 2006); and to their role in the absorption of GHG, which is important for carbon mitigation. Both categories include fresh and processed F&V, excluding juices. **Bottled water** was included for the lower footprint of its closest substitute, tap water (Botto *et al*., 2011; Pasqualino *et al*., 2011): consumers could reduce their footprint substantially in this market by avoiding unnecessary plastic packaging. Sales refer to any type of water (including flavoured water). Finally, **online shopping** is important in reducing the high environmental impact of food shopping (Edwards *et al.*, 2010; Coley *et al.*, 2009). This category refers to any food and drink (F&D) product purchased online. Alcoholic drinks are excluded from total F&D. See Defra (2010) and Sustain (2007) for more details on these categories.

3.2. Data

The application is based on weekly expenditures for the six food categories distinguished in section 4.1 over the period June 2009-May 2011. Data for the empirical exercise are supermarket scanner data for food purchases in Tesco supermarkets across the UK. Descriptive statistics of the six food categories are given in Table 1. Tesco is the largest retailer in the United Kingdom, with an overall market share of 30.5-30.8% in value over 2010 and 2011[3]. Hence the dataset (Tesco Clubcard data) is a large source of information, containing a record of all purchases of Tesco's 16-17 millions UK cardholders.)

4.3 Identification of social norms

As discussed in section 2, eqn (3), we use the modus of observed consumption behaviour in each food category as the social norm. Thus C^{modus} for food category *j* is determined observing the expenditures patterns of a representative sub-sample of 100,989 Tesco customers in the UK in the year 2011. As shown in Figure 2 the resulting thresholds for each category are:

- ***Meat:*** ≤ 20% of total F&D budget spent on meat;
- ***Red meat:*** ≤ 70% of total meat budget spent on red meat;
- ***F&V:*** ≥ 20% of total F&D budget spent on F&V;
- ***Organic F&V:*** ≥ 10% of total F&V budget spent on organic F&V;

[3] http://www.guardian.co.uk/business/2011/aug/16/supermarkets-market-share-kantar

- ***Bottled water:*** ≤ 10% of total F&D budget spent on bottled water;
- ***Online shopping:*** ≥ 10% of total F&D budget spent online.

4.4 ESS and habitual consumption

Descriptive statistics of the six food categories (Table 1) indicate that the normalisation procedure substantially changes the distribution of all food categories: all averages become smaller for "dirty" and larger for "clean" options; while all variances increase. The panels on the right handside of figure 3 depict the ESS index after the adjustment for habitual consumption in each food category. Descriptive statistics of the six food categories (Table 1) indicate that the normalisation procedure substantially changes the distribution of all series. Firstly, all variances increase as a consequence of the correction for the historical maximum and minimum, which rescales the whole series within the actual observed range of consumption. Furthermore, table 1 indicates that all averages become smaller for dirty and larger for clean options. This change is a consequence of higher initial values of sustainable consumption in dirty categories 297 compared to clean ones. Also, clean categories tend to be on average more distant from the historical minimum of sustainable consumption than dirty ones (with the exception of online food shopping), representing a larger share relative to the historical range. As a result, the habit transformation reveals that in our data clean categories are consumed more sustainably than dirty ones in relative terms, and the low absolute values associated with these levels of consumption suggest that there is a substantial room for improvements.

4.5 Trends in sustainable food consumption according to the ESS index

Figure 3 presents and compares all versions of the indicator using weekly expenditure data. Graphs indicate that all versions of the ESS index have similar time trends, with local maxima and minima appearing roughly at the same point in time. The only relevant distinction is the normalised geometric mean, which tends to "underestimate the negatives": it is undefined at zero, and these lowest points are removed, despite being non-zero minima in the remaining versions. Figure 3 also shows that the overall level of sustainability in food purchasing decreases over the course of the year in two periods: at the beginning of winter (Christmas and New Year festivities); and over summer (July, August). Highest performances appear to occur in the first quarter of the year. Just observing these graphs, sustainability appears to have a cyclical yearly structure, a type of dynamics that will require attention in future research.

4. VALIDATION OF THE ESS INDEX

As mentioned in the introduction, this study is the first to present an indicator aiming at measuring sustainable consumption with food expenditure data. The immediate consequence of this novelty is that the ESS index needs to be validated. Validation implies providing an assessment of its ability to measure sustainable consumption. This process includes: design validation to evaluate if the index is scientifically founded; and output validation to assess the soundness of the index results. This section also establishes to what extent the three versions of the index can be substitutes for each other.

5.1 Validity

Three types of validity are distinguished: criterion validity, content validity and construct validity (see Kaplan et al., 1976). ***Criterion validity*** refers to the ability of the indicator to accurately represent the phenomenon in analysis by comparing well to an existing reliable measure. Due to the absence of another sustainable food consumption indicator, such a comparison is not straightforward. To make the task feasible, the ESS is compared against an estimate of its GHG emissions: expenditures in each class (meat, F&V, bottled water and online shopping) are multiplied by the estimated weight per £ of sales[4] and then by their LCA estimates (table 2). These estimates have been derived using CCaLC (CCaLC, 2012), a repository of LCA measures. Carbon footprint values in CCaLC include all greenhouse gases, which are then converted into CO_2eq[5].

Results in Table 3 indicate a significantly negative correlation between emissions and ESS index. This trend is determined by meat consumption, while emissions from water and F&V correlate positively to the index. Observing all other indicators, the percentage of customers reusing plastic bags and shopping online correlate positively with the ESS, while total food sales (online and not) correlate negatively. Apart from water, all coefficients have the expected sign.

Construct validity refers to the need of a detailed definition of the phenomenon being measured in order to define the validity of the indicator. In essence, construct validity would maintain that it is impossible to define a sustainable consumption indicator without a clear and valid definition of sustainable consumption. The selection of dirty and clean food products categories in the index relied on external sources, and construct validity as far as the selection of category is concerned refers directly to the references in section 4.1. In contrast this literature does not provide information on the thresholds for the definition of sustainable consumption and thus these were chosen on the basis of revealed consumer behaviour.

Finally, ***content validity*** refers to the ability of the indicator to represent adequately the domain it intends to analyse. Content validity was measured as the correlation between the resulting ESS index and each of its components. The results in Table 4 refer to Pearson correlations; we also explored Spearman and Kendall's tau-b correlations which led to comparable findings. These results indicate that sustainable consumption in each category correlates positively to all versions of ESS, with the only notable exception of bottled water

[4] Conversion rates were obtained from DEFRA's family survey as: Meat = 0.17 kg/£; F&V = 0.51 kg/£; Water = 2.48 kg/£; Total F&D: 0.33 kg/£. See http://www.defra.gov.uk/statistics/foodfarm/food/familyfood/datasets/.

[5] We are indebted to Harish Jeswani for support with this data.

(negatively correlated to the ESS) and meat (occasionally uncorrelated to the ESS). The counterintuitive result for bottled water is caused by a negative correlation between sustainability in this category and sales in F&V, suggesting that sustainability in these two markets are substitutes. This idea is confirmed observing a negative correlation between the percentage of sustainable households in the water market and in the market for F&V (-0.72) and organic F&V (-0.50); as well as considering sustainable consumption of water ($1\text{-}w_{water}$) and that of F&V (-0.73) and organic F&V (-0.66). An alternative explanation could be that consumption of bottled water is not driven by environmental concerns, but rather substitute needs (e.g. health, taste, or convenience when travelling)[6]. Identical results were found correlating the ESS index with average consumer expenditures for the same six food categories[7].

The validity of the ESS index can be also assessed by observing whether there are significant seasonal variations in its median and distribution. Figure 4 suggests that winter and summer might be weaker periods, and this seasonal dependence was confirmed by a Kruskal-Wallis test[8] (Table 5). The Kruskal-Wallis test also indicates that the mean of the ESS tend to decrease across quartiles of food expenditures (a proxy for household income) and across quartiles of total meat expenditures (a less sustainable food), while it increases over total F&V (a more sustainable food) expenditures. Results hold across aggregating function.

5.2 Internal consistency and reliability

The second step of the assessment on the ESS index is an evaluation of internal consistency and reliability. Consistency refers to the ability of an indicator to measure the same general construct. Internal consistency of the eight versions of the indicator was

[6] We are grateful for an anonymous referee for highlighting this point.
[7] Results are available upon request.
[8] Very similar results have been observed doing a median test.

evaluated using Cronbach's alpha[9]. Results indicate that all 12 versions of ESS index reflect the same underlying construct, with a Cronbach's alpha of 0.80. Breaking down the analysis, the Cronbach's alpha for each of the four blocks of ESS versions (i.e. linear vs binary; normalised vs non-normalised) remains high: it is 0.76 for the three ESS-lin versions, and 0.65 for their three normalised versions; and 0.65 for the three ESS-bin versions, and 0.65 for their three normalised ESS-bin. Further support for internal consistency comes from the results of a principal component analysis (PCA). The 12 versions of ESS are reduced into a single factor, which explains 79.23% of the overall variance.

Similarly, reliability entails testing the ability of the ESS index to consistently and effectively measure sustainability over time. Yearly consistency is tested splitting all series into two subseries of equal length. The resulting Spearman-Brown coefficient is high for all 12 series (going from 0.64 to 0.93), which indicates that the yearly trend of sustainability is repeated over time. Comparing the 12 (full-length) series across versions, the Spearman-Brown Split-Half coefficient appears high (0.93) when comparing the six normalised versions together with the six non-normalised versions; treating the four groups separately and correlating them one by one, the six Spearman-Brown Split-Half coefficients remain high, between 0.87 and 0.97. Finally, internal consistency is supported by generally highly positive and significant coefficients of correlation in the repeatability test (Test-retest) between the different versions of the ESS index.[10]

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[9] Cronbach's alpha is a measure of internal consistency commonly used to determine the reliability of scales or variables (questions, raters, indicators, etc.) on the interest to know to what extent they "measure the same thing." The coefficient is defined as $\alpha = \frac{K}{K-1}\left(1 - \frac{\sum_{i=1}^{K}\sigma_{Y_i}^2}{\sigma_X^2}\right)$, where K indicates the number of components, σ_X^2 is the variance of the observed total test scores, while $\sigma_{Y_i}^2$ is the variance of *i*th component.

[10] Results are available upon request.

5. DISCUSSION AND CONCLUSIONS

5.1. Food category selection and end use behaviour

The ESS index has been estimated by aggregating six classes of products that UK policymakers consider having important implications in sustainable consumption on the basis of existing research. However, future research may disprove current beliefs and target different categories; or the implementation of current policies targeting food consumption may be successful and lead to scenarios with different priorities for sustainability. Undoubtedly, sustainability accounts for a broader range of food products than the six categories considered here, but the ESS index aims at revealing whether UK food consumption is sustainable in relative rather than absolute terms, giving a measure of sustainability by comparing revealed behaviour against published advice on sustainable consumption.

A limitation of the ESS index is its inability, in the form presented in this article, to include end use behaviour, particularly cooking and food waste. A more complete consumption perspective can be found in Druckman and Jackson (2009, 2010) who include for instance emissions from cooking, dishwashing, and travel to shops. Consequently, the index implicitly assumes constant end use emissions per unit of sales across category, an assumption that needs further analysis in future research.

Despite these caveats, we feel that the strength of the approach proposed in this paper is that it offers a flexible framework: it can be adapted to include and exclude food categories as appropriate, along the same line as the dynamic basket used for the Consumer Price Index. This generalisation could also include end use emissions (e.g. from cooking and waste). .

6.2 Comparison of indicator versions

Tests of validity or reliability indicated that all versions of the index measure sustainable consumption. However the different versions of the index do not provide an identical measure of sustainability despite representing the same underlying construct (as expected by construction). Consequently, assumptions on the proportional or non proportional environmental impacts, the correction for habitual consumption and the aggregation procedure take on more importance. Results give some indications on the performance of each aggregating function: the ESS from summation and average mean are the simplest to interpret, while the geometric mean version of the index seems weaker because it removes zeros when data are normalised. Nevertheless, further research should consider the implications of these differences as no version at this point can be determined as superior in terms of validity or reliability in performance.

5.2. The data

Whereas it is a very important source of information, the use of scanner data recorded by a single retailer has some limitations. Not all UK citizens shop at Tesco, and thus the sample in consideration might not be entirely representative of the total population. Firstly, there could be a selectivity bias if Tesco consumers have a different sensibility towards the environment compared to the average population. However, Tesco is present across the country and reaches a wide variety of consumers: the data records purchases of around 17 million UK cardholders, catering for a good sample of individuals. In particular, its target customers should exclude consumers in the extreme side of the spectrum, i.e. those shopping regularly in very expensive or value retail chains. Importantly, this dataset includes a share of population significantly larger than the response rates commonly achieved in survey management.

Secondly, the data does not account for switching behaviour. Consumers may shop in more than one retailer, deciding where to shop depending on their needs. For instance, they may do the general shopping in store brand A but purchase those products with significant environmental implications elsewhere (e.g. store brand B, or a farmer market). This entails that the overall environmental performance of a consumer based on her shopping at Tesco might understate the real environmental sensibility of the shopper.

Finally, it should be noted that scanner data as used in this paper is an imperfect tool to collect individual preferences. The card owner is not always the choice-maker and women tend to be more often associated with the role of gatekeeper, being more often responsible of the food shopping. As a result, the data represents a consumer's choices in terms of a more complex structure of preferences: the underlying utility of consumption does not refer to the preference of the gatekeeper, but it also incorporates the needs and tastes of the whole household (Miller, 1998).

6.3 Conclusions

The contribution of the ESS index can be summarised as follows. First, this study is a first step to summarise the impact of revealed consumer behaviour using an index for food purchases based on supermarket data. The index can be used to proxy sustainable consumption at the end of the food chain (the level of the consumer) both through cross-sectional and time series analysis (including repeated cross-sectional analysis). This tool enables a systematic monitoring of the environmental impact of food sales. The resulting information can be used to maintain and enhance sustainability in household consumption through marketing strategies, for instance through promotion of environmental quality in those critical periods identified by the index (Christmas and summer for the UK).

Second, the ESS index can be used in studies on changes in aggregate sustainability of food shopping at different points in time and under different circumstances. Here the index including the social norm can be useful in particular. The objective of a policy with respect to such a threshold would be two-fold. First, consumers above the mode should be shifted towards the mode. Second the mode as such should be shifted towards a more socially optimal environmentally (and nutritionally) optimal level of consumption. Examples of such studies could include the use of econometric scenario-making (e.g. micro-simulation modelling) at household and consumer level, to observe changes in choice and welfare as a consequence of governmental intervention. In addition, the index can be further extended to separate different stages of demand formation, isolating the choice decision from the quantity decision (as suggested in Fiala, 2008).

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FIGURES

Figure 1: Graphical representation of the design process of the ESS index

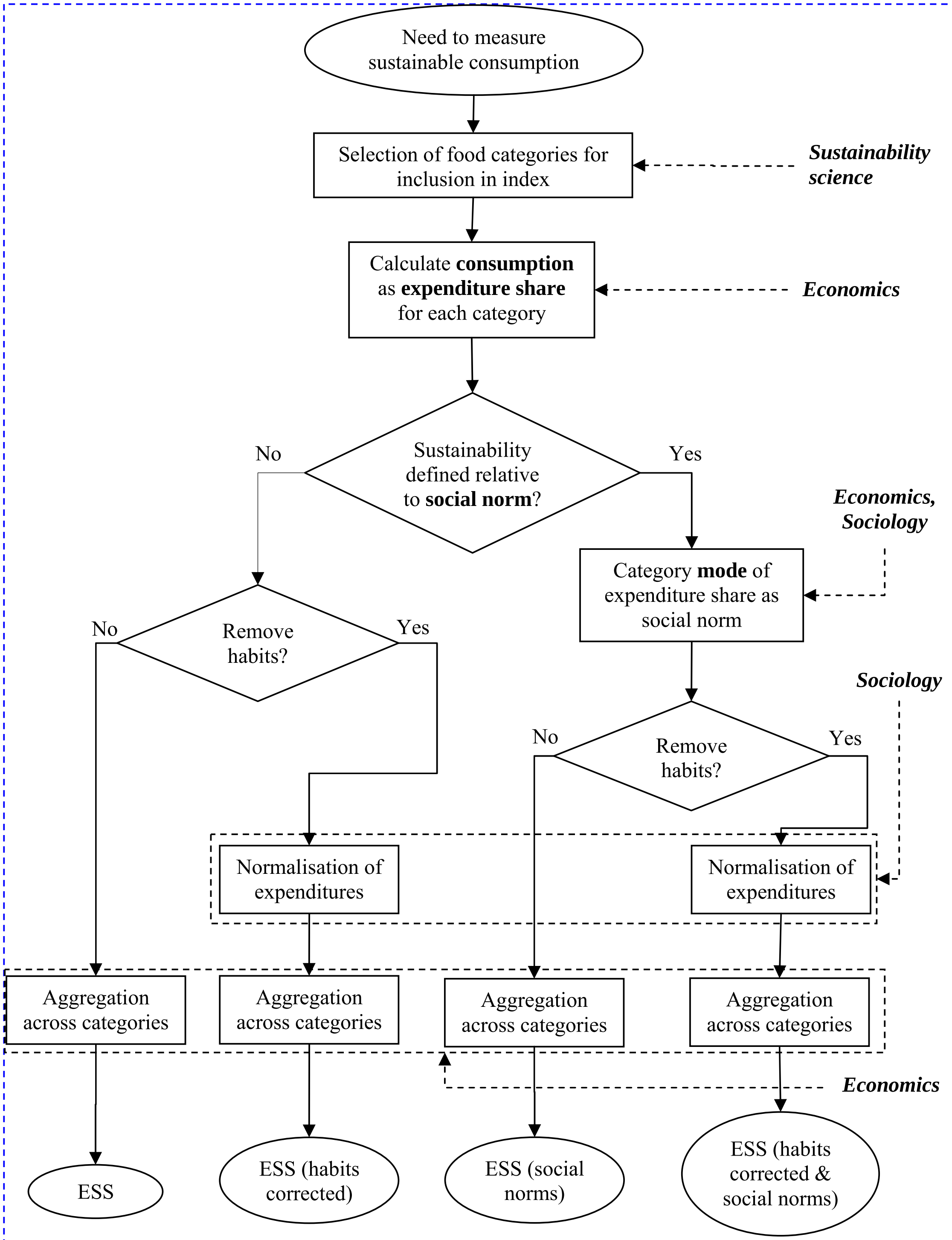
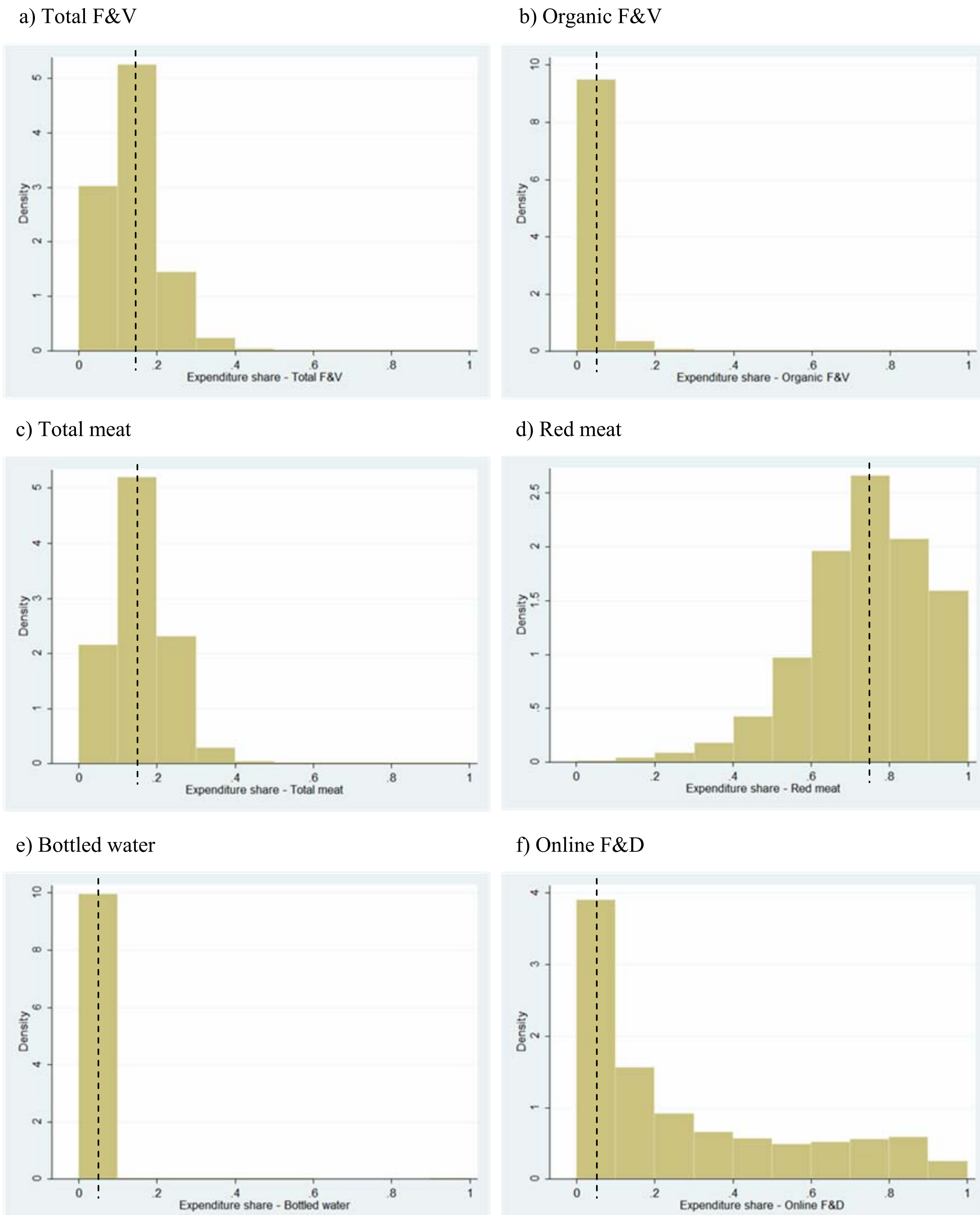


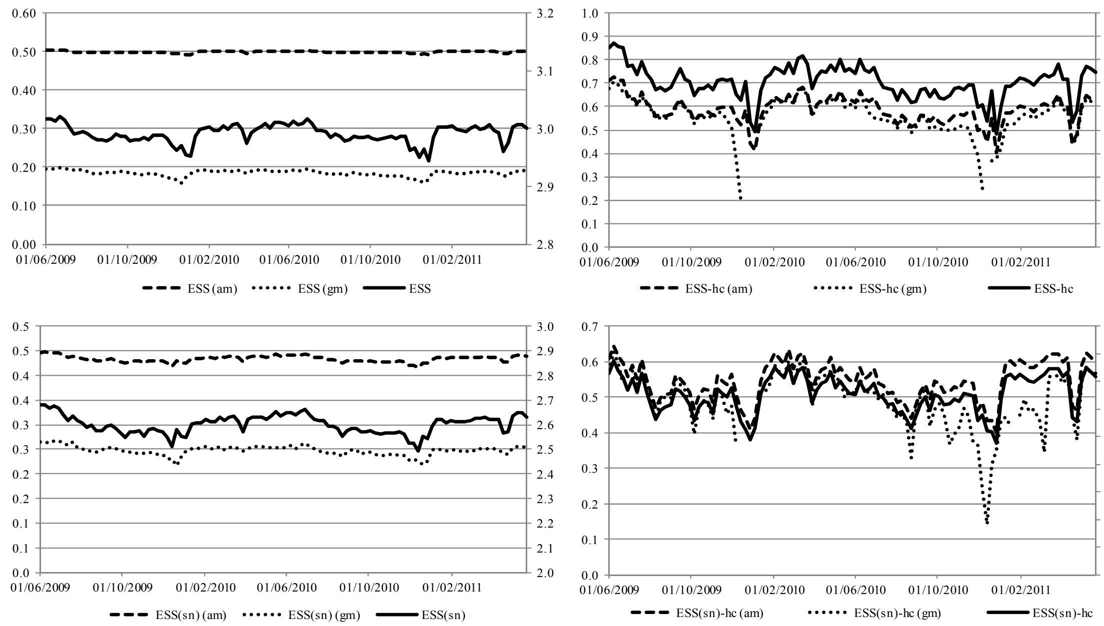
Figure 2: Modus of expenditure patterns by food category



Notes: N = 100,989 UK consumers; zeros excluded from analysis.
The dashed line indicates the mode of the distribution.

Figure 3: Graphic comparison of different versions of the ESS index (weekly data)

a) Habitual consumption not removed b) Habitual consumption removed



Note: in each graph the y-axis on the right hand side refers to the sum version of the specific ESS indexes. Abbreviations are as follows: ESS-hc = ESS with habits correction; ESS(sn) = ESS based on social norms; ESS(sn)-hc = ESS based on social norms with habits correction. The abbreviations (am) and (gm) indicate an aggregation by arithmetic mean or geometric mean.

TABLES

Table 1: Summary of food product categories selected to construct the ESS index

Item	*Category*	*Reference*		*Mean*	*S.D.*	*Min*	*Max*
Exp. Share	Meat	Total F&D	Before	0.8604	0.0051	0.8379	0.8738
	Red meat	Total Meat	Normalisation	0.9078	0.0035	0.8918	0.9184
	Water	Total F&D		0.9946	0.0009	0.9913	0.9973
	F&V	Total F&D		0.1521	0.0129	0.1127	0.1741
	Organic F&V	Total F&V		0.0048	0.0008	0.0032	0.0070
	Online shopping	Total F&D		0.0715	0.0074	0.0398	0.0863
	Meat	Total F&D	After	0.6277	0.1426	0.0000	1.0000
	Red meat	Total Meat	Normalisation	0.6026	0.1332	0.0000	1.0000
	Water	Total F&D		0.5527	0.1578	0.0000	1.0000
	F&V	Total F&D		0.6813	0.1599	0.0000	1.0000
	Organic F&V	Total F&V		0.6426	0.2099	0.0000	1.0000
	Online shopping	Total F&D		0.4166	0.1953	0.0000	1.0000
% of	Meat	Total F&D	Before	0.5581	0.0145	0.4878	0.6139
Sustainable	Red meat	Total Meat	Normalisation	0.6778	0.0105	0.6501	0.7039
Households	Water	Total F&D		0.9835	0.0036	0.9700	0.9916
	F&V	Total F&D		0.0367	0.0037	0.0192	0.0433
	Organic F&V	Total F&V		0.2847	0.0358	0.1864	0.3551
	Online shopping	Total F&D		0.0599	0.0083	0.0479	0.0932
	Meat	Total F&D	After	0.5572	0.1148	0.0000	1.0000
	Red meat	Total Meat	Normalisation	0.5162	0.1946	0.0000	1.0000
	Water	Total F&D		0.6272	0.1646	0.0000	1.0000
	F&V	Total F&D		0.7279	0.1538	0.0000	1.0000
	Organic F&V	Total F&V		0.5827	0.2124	0.0000	1.0000
	Online shopping	Total F&D		0.2646	0.1839	0.0000	1.0000

Table 2: Average carbon footprint per category and relative weights

Category	*Kg CO2/Kg items*	*Source:*
Total Meat; and Red meat	9.46	CCaLC (2012)
Bottled water	0.31	CCaLC (2012)
Food shopping*	0.09	Ecoinvent (2010)
Total F&V; and Organic F&V	0.16	CCaLC (2012)

* The estimated carbon foot print for online food shopping is calculated as follows. Total CO2 for transport is calculated knowing the average transport distance from retailer to household (7.81 km, see Berlin and Sund, 2010, page 23) multiplied by carbon footprint per km of an average petrol car (0.237 kg/km) (Ecoinvent database 2010). The resulting value has been doubled to account for a return journey, and assumes 59% of consumers shopping without a car (see Berlin and Sund, 2010, page 23). The total amount of food purchased corresponds to 10.03 kg of food per person per week (2010 estimates from DEFRA's Family and living costs survey, see http://www.defra.gov.uk/statistics/foodfarm/food/familyfood/datasets/), which has been multiplied by 2.4 (average household size, see http://www.ons.gov.uk/ons/rel/family-demography/families-and-households/2011/stb-families-households.html#tab-Household-size). The final value corresponds to the ratio of these two estimates.

Table 3: Correlation between ESS index and other indicators of sustainable consumption

	% consumers		*Sales*		*CO2*			
	Reusing bags	**Shopping online**	**Total food**	**Online food**	**Total**	**Meat**	**F&V**	**Bottled water**
ESS	0.2584***	0.4540***	-0.4288***	-0.2301**	-0.4643***	-0.5240***	0.4493***	0.5413***
ESS (gm)	0.4688***	0.3150***	-0.7124***	-0.5452***	-0.5804***	-0.6319***	0.3015***	0.5689***
ESS(sn)	0.1836*	0.1709*	-0.4813***	-0.2062**	-0.3971***	-0.4642***	0.5955***	0.6325***
ESS(sn) (gm)	0.4788***	0.2816***	-0.6149***	-0.4939***	-0.5384***	-0.5933*	0.3335***	0.6282***
ESS/hc	0.3453***	0.2752***	-0.2602***	-0.0938	-0.4856***	-0.5281*	0.3288***	0.3116***
ESS/hc (gm)	0.2728***	0.3343***	-0.5289***	-0.4755***	-0.6675***	-0.6858***	-0.0311	0.1805*
ESS(sn)/hc	0.1492	0.6052***	-0.3493***	-0.2728***	-0.4319***	-0.4651***	0.2069**	0.1955**
ESS(sn)/hc (gm)	0.2497**	0.3235***	-0.4037***	-0.3723***	-0.5462***	-0.5653***	-0.0030	0.2130**

*, **, ***: significance at 10%- , 5%- , or 1%-level respectively (2-tailed). Versions based on arithmetic averages are removed from the table because their coefficients are identical to their summation counterparts. Abbreviations are as follows: ESS-hc = ESS with habits correction; ESS(sn) = ESS based on social norms; ESS(sn)-hc = ESS based on social norms with habits correction.

Table 4: Pearson correlation between the ESS index and its component food product categories (original variable)

a) Sustainable consumption based on expenditure shares

Initial variable	*Food expenditure share in the following category:*					
	1-Total meat	*1-Red meat*	*1-Bottled water*	*Total F&V*	*Organic F&V*	*Online F&D*
ESS	0.1582	0.3702***	-0.6228***	0.7678***	0.5207***	0.5007***
ESS (gm)	-0.1733*	-0.0947	-0.7307***	0.8573***	0.8168***	0.4148***
ESS-hc (n)	0.4631***	0.5691***	-0.3868***	0.5450***	0.5935***	0.2984***
ESS-hc (gm)(n)	0.0802	0.1676*	-0.3559***	0.4818***	0.4669***	0.3662***
Total F&D exp	0.3284***	0.3490***	0.4821***	-0.5143***	-0.5075***	-0.3978***
Total meat exp	-0.1477	-0.0674	0.4805***	-0.3975***	-0.5498***	-0.2782***
Red meat exp	-0.1123	-0.1627*	0.4999***	-0.4763***	-0.4987***	-0.3691***
Total F&V exp	-0.0208	0.1775*	-0.3709***	0.6237***	0.2870***	-0.1947**
Organic F&V exp	0.1904*	0.0809	-0.5548***	0.5812***	0.9101***	-0.3302***
Total water exp	0.0626	0.1150	-0.9481***	0.6288***	0.5304***	0.0101
Online F&D exp	-0.0620	0.1450	0.1875*	-0.2045**	-0.4753***	0.7831***

*, **, ***: significance at 10%- , 5%- , or 1%-level respectively (2-tailed). Versions based on arithmetic averages are removed from the table because their coefficients are identical to their summation counterparts. Note: for total meat, red meat, and bottled water expenditure shares refer to *$(1-w_{jt})$*, to capture sustainable consumption within the category. Abbreviations are as follows: ESS-hc = ESS with habits correction.

b) Sustainable consumption based on social norms

Initial variable	*% of Sustainable households in the following category:*					
	Total meat	*Red meat*	*Bottled water*	*Total F&V*	*Organic F&V*	*Online F&D*
ESS(sn)	0.0103	0.3615***	-0.6726***	0.8900***	0.4418***	0.1747*
ESS(sn) (gm)	-0.2116**	0.1991**	-0.6925***	0.8125***	0.6512***	0.3609***
ESS(sn)-hc	0.0101	0.6687***	-0.2388**	0.5255***	0.2082**	0.6035***
ESS(sn)-hc (n)	0.0046	0.4020***	-0.3030***	0.3725***	0.3205***	0.2537***
Total F&D exp	0.4476***	-0.2394**	0.3669***	-0.4524***	-0.3171***	-0.3406***
Total meat exp	0.0067	-0.1750*	0.4022***	-0.3567***	-0.4425***	-0.2045**
Red meat exp	0.0363	-0.3799***	0.4129***	-0.4291***	-0.3445***	-0.2794***
Total F&V exp	-0.0389	0.0198	-0.4007***	0.6684***	0.1203	-0.1837*
Organic F&V exp	0.0806	-0.3440***	-0.5782***	0.6099***	0.8865***	-0.2930***
Total water exp	-0.1177	0.0604	-0.9636***	0.6956***	0.4051***	0.0235
Online F&D exp	-0.0064	0.5126***	0.2042**	-0.1929**	-0.5359***	0.8142***

*, **, ***: significance at 10%- , 5%- , or 1%-level respectively (2-tailed). Versions based on arithmetic averages are removed from the table because their coefficients are identical to their summation counterparts. Abbreviations are as follows: ESS(sn) = ESS based on social norms; ESS(sn)-hc = ESS based on social norms with habits correction.

Table 5: Independent samples Kruskal-Wallis test by season and expenditure quartiles

	Season	*F&D expenditures*	*Meat expenditures*	*F&V expenditures*
Main Trend	Downward-facing parabola	Decreasing	Decreasing	Increasing
ESS	34.264***	10.315**	16.189***	40.828***
ESS (gm)	39.408***	14.489***	19.933***	29.352***
ESS-hc (n)	27.922***	5.244	18.103***	17.372***
ESS-hc (n) (gm)	33.090***	13.489***	24.703***	8.452**
ESS(sn)	51.421***	10.450**	13.819***	48.311***
ESS(sn) (gm)	42.594***	9.718**	16.657***	28.442***
ESS(sn)-hc	33.655***	8.691**	9.690**	19.880***
ESS(sn)-hc (gm)	50.507***	10.191**	17.232***	6.311*

*, **, ***: significance at 10%- , 5%- , or 1%-level respectively (2-tailed). Versions based on arithmetic averages are removed from the table because their coefficients are identical to their summation counterparts. Abbreviations are as follows: ESS-hc = ESS with habits correction; ESS(sn) = ESS based on social norms; ESS(sn)-hc = ESS based on social norms with habits correction.